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Published in:

Proceedings of the 8th International Symposium on Advanced Topics in Electrical Engineering

DOI:

[10.1109/ATEE.2013.6563411](https://doi.org/10.1109/ATEE.2013.6563411)

Publication date:

2013

Document Version

Peer reviewed version

[Link to publication in Discovery Research Portal](#)

Citation for published version (APA):

Dastoori, K., Al-Shabaan, G., Kolhe, M., Thompson, D., & Makin, B. (2013). Charge Measurement of Dust Particles on Photovoltaic Module. In *Proceedings of the 8th International Symposium on Advanced Topics in Electrical Engineering* (pp. 1-4). IEEE. <https://doi.org/10.1109/ATEE.2013.6563411>

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Charge Measurement of Dust Particles on Photovoltaic Module

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Abstract- Photovoltaic (PV) systems are one of the most promising renewable energy sources in the world, and hence it is important to explore the factors that affect the working / operational efficiency of this source. Many factors can affect the efficiency of the solar cells such as: dust accumulation on the surface of the arrays; cell material; shading; tilt angle of the cells; orientation of the PV modules and cell temperatures. This research is focused on the analyzing the effect of charged dust particles on the PV module performance. A number of studies have demonstrated the effect of dust accumulation on the PV modules' performance. But the relation between the amounts of charge of the dust particles and the PV module performance is still not well investigated. Various experiments conducted during this research work to investigate the relation between the amount of charge of the dust particles and their impact on percentage reduction of the PV modules' output voltages. The experimental results have shown that the charged particles have significant impact on PV modules' output voltages and also accumulation of charged dust particles has not any impact of PV modules' tilt angles.

Keywords: Photovoltaic, Charge measurements, charge impact of dust particles

I. INTRODUCTION

With today's solar photovoltaic (PV) efficiencies, solar energy from desert areas would be more than enough to meet the electricity demand [1]. PV system is one of the most promising renewable energy sources in the world, and hence it is important to explore the factors that affect the working / operational efficiency of this energy source. Solar PV cells cannot achieve 100% energy conversion efficiency, because they respond to a narrow bandwidth of the sunlight's spectrum (i.e. wavelengths). Photons with energy less than the energy of the solar cells material's band gap are not absorbed. There are many environmental factors that affect the PV system performance. The solar PV system performance ratio depends on the solar cell temperature factor, load matching factor, inverter mismatch factor, etc [2]. Especially in the desert area, where large scale PV system are under planning, dust accumulation on the PV modules would have significant impact on system performance [3]. Dust accumulation to a surface mainly depends on the dust particle size, electrostatic charge, and the presence or absence of an

adsorbed moisture layer, the electrical resistivity of the dust particles [4, 5].

A number of studies [3-8] have demonstrated the effect of dust accumulation on the PV cell's efficiency. Refs [9, 10] have investigated the effects of electrostatically charged dust on the efficiency of a PV module for extra-terrestrial satellite in the Martian atmosphere. They [9, 10] have confirmed that the accumulation of dust on the PV module's surface has significant loss in PV module's efficiency. These contributions have not provided any quantitative analysis about the effect of charge levels of dust particles on the PV module's performance. The relation between the amounts of charge on the dust particles and the PV module's efficiency are required for further investigation. This analysis will help in finding the impact of dust particles on the performance of PV system applications in the desert areas.

In this work, various experiments have been conducted to investigate the relation between the amounts of charge of the powder (i.e. dust) particles and hence the percentage of reduction on the PV modules' output voltages. The experiments have been done using an array of Faraday cups (FCs), LabVIEW software in conjunction with DAQ device, and an electronic interface circuit. This design has been reported in the work. [5, 8, 11] Two charging processes (i.e. corona charging and tribo charging [11]) have been used, for changing the charge levels of the dust particles on the PV module.

II. CHARGE MEASUREMENT METHOD

In this work, the charge amount of accumulated particles on the PV module has been measured for analyzing the impact of charge level of dust particles on the PV module's output voltages. In this study, epoxy powder has been used as dust particles. Three amorphous-silicon PV modules have been tested under laboratory conditions. The experiments have been carried out for (i) clean room conditions (ii) electrostatically charged dust particles on PV modules' surfaces. Two sets of tests have been carried out on each PV module. For the first test, each PV module's output voltage has been measured under clean-room conditions. For the second set of tests, each PV module has been coated by spraying electrostatically charged particles to simulate the

accumulation of equivalent dust particles on the surface of the same PV module in operation under stormy (e.g. desert) conditions. In these tests, epoxy powder has been used to simulate the expected conditions that may arise in a desert location. Data acquisition has been realized by using specially designed electronic interface unit linked to LABVIEW [8]. The Faraday Cup (FC) design has been reported in [5, 8, 11, 12]. A three dimensional draft for the substrate has shown in Fig. 1(a) and FC array after the electroless Nickel plating has given in Fig 1(b).

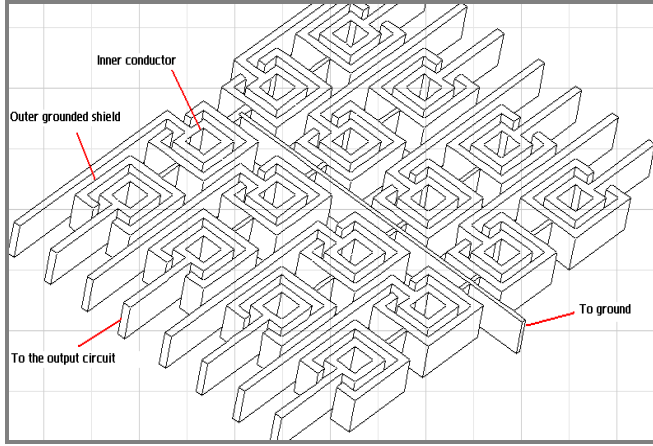


Figure 1a. Three dimensional drafts for the substrate

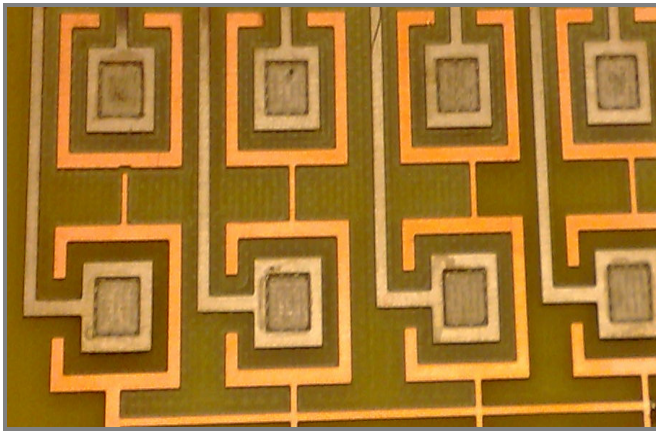


Figure 1b. FC array after the electroless Nickel plating

A. Experimental Method

For these tests, a procedure to determine the amount charge on the accumulated dusts has been developed. A measuring instrument has been designed and used to carry out measurements of the effects of charged powder particles on a PV module's output voltage. The instrument consisted of an array of static Faraday Cups on an FR4-PCB has been shown in Fig 1b. The net charge on the accumulated powder particles by individual cups in the array has been measured. For these measurements a DAQ device in conjunction with the LabVIEW software has been used to collect and display the charge accumulated within each FC. A multifunction

6008 USB DAQ device has been used to connect the FC outputs to the PC with its LABVIEW software for data acquisition and analysis. The details of these experimental methods have been reported in the ref [12].

B. Procedure

The experiments have been carried out using three amorphous PV modules with different dimensions. The first amorphous PV module (PV1) has dimension of 28 x 70 cm dimensions, the second PV module (PV2) has dimension of 15 x 5.5 cm dimensions, while the last (PV3) has dimension 1.25 x 1.65 cm. Each PV module has tested before coating the charged powder in the clean room conditions and then with the coating of the charged particles. These tests have been carried out by measuring the output voltages of each PV module before and after being coated with the charged powder.

In this study, the electrostatically charged epoxy powder has been used. The measurement techniques consisted of spraying the epoxy powder using a powder gun onto the FCs array. In all experiments, a PV module has been coated for a period of 7 seconds. As for electrostatic powder coating, the adhesion properties of the powder for both corona and tribo spraying systems have been kept equal to 6–7 seconds [5, 8, 11, 12]. Two types of electrostatically generated charged clouds have been used: (i) tribo and (ii) corona sources. The source voltages have been set in the range 20 – 70 kV and investigations have been carried out at 10-kV intervals [12].

Four sets of experiments have been carried out for this work. For corona charging, all experiments have been done with a constant pressure (i.e. 2 bar) and different voltage values varying from 20kV to 70kV (10kV increment each time). Moreover, for the tribo charging, the powder have been charged using different amounts of pressures varying from 1 bar to 2 bar with 0.5 bar increment for each experiment. The distance between the nozzle of the spraying gun and the FCs array and the PV module has been fixed at 27 cm for all experiments. The PV module and the FCs array have been attached vertically to the grounded wall for making tilt angle 90° .

After each experiment the coating system has been switched off, and the FC array and then the PV module have been connected to the DAQ system through the interface electronic circuit. The output measurements for the powder charge from the FC array and the output voltages for the PV modules have then displayed on the PC, and saved to a backup file that has been recorded by LabVIEW software. After acquiring the measurement results, the PV module and the FC arrays have been then cleaned of the adhered charged powder. An air pressure nozzle has used for cleaning purposes. Another cleaning process has used to clean the PV module by using dry tissues to wipe the area that has been covered by the charged powder. This has been applied before using the water and the air pressure nozzles to clean the PV-modules. The results from each set of data have been

analyzed statistically to determine a correlation coefficient (i.e. *R-squared*).

III. EXPERIMENTAL RESULTS

Three PV modules denoted PV1, PV2 and PV3 have been investigated for their open-circuit voltages under clean room and accumulated charged dust particles conditions. Under clean room conditions, the open circuit voltages were 8.1, 8.1 and 0.79 volts respectively. The regression curve for the relationship between the charge per cup values obtained from FCs array and PV modules' output voltages after being coated using the corona charging gun and it has been given in Fig.2. The regression curve for the relationship between the charge per cup values obtained from FCs array and PV modules' output voltages after being coated using the tribo charging gun has been obtained and it has been shown in Fig.3.

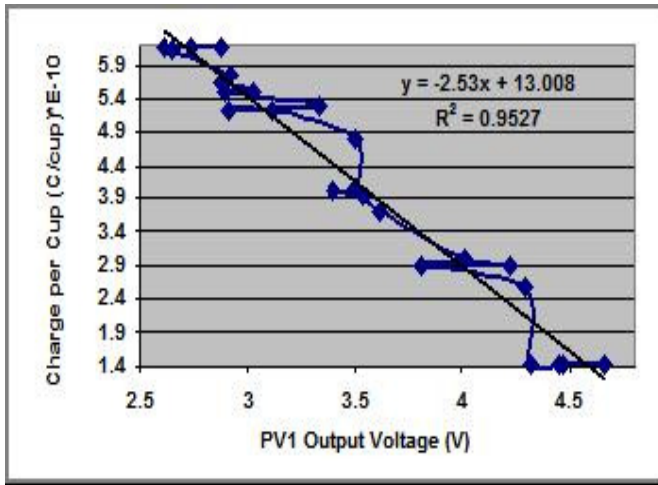


Figure 2: PV1 output voltage and the amount of charge per cup for FCs Array as obtained after Corona Charging process.

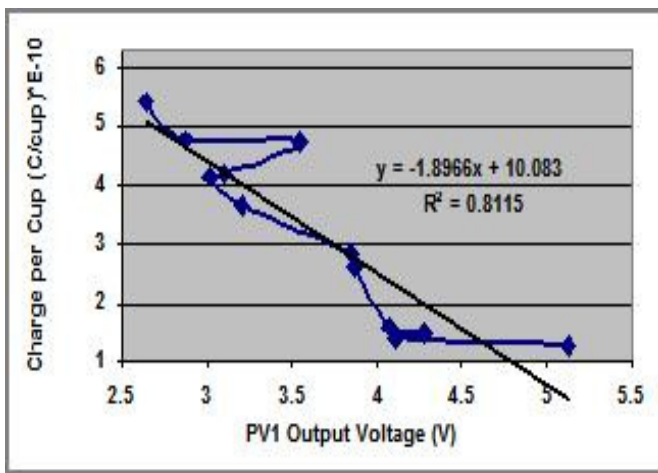


Figure 3: PV1 output voltage and the amount of charge per cup for FCs array as obtained after Tribo Charging process.

It has been observed through Figures 3 and 4 that by increasing the amount of charge per cup (which indicates the amount of charge deposited on the different PV module

surfaces) causes a decrease in the output voltage. The *R-squared* value shows a linear relationship between the charges per cup values with PV1 output voltages, even though the results show clear evidence of localized non-linear relationships at different locations on each graph. Such differences between the results are believed to be related to the changes in the relative humidity throughout the experiments (a factor which is known to affect the powder deposition rate). There are two main mechanisms, which usually affect the powder deposition on the surfaces and they are gravitational settling and electrostatic mechanisms [5, 7].

Based on the obtained experimental results, it has been observed that there is significant impact of charge levels of dust accumulations on the reduction of PV module's output voltages. Coating of the PV modules' surfaces with epoxy powder charged at 70 kV, results in almost complete coverage of the PV modules' surfaces, and also it leads to a decrease in the output voltage of around 68 % for PV1, 64% for PV2, and 30% for PV3 with respect to the clean room conditions. After the tribo charging process, the obtained results have demonstrated that the powder with highest amount of charge values reduced the PV modules' output voltages by 67%, 69%, and 35% for PV1, PV2, and PV3 respectively.

IV. CONCLUSIONS

In this work, different experiments have been conducted to investigate the relation between the amount of charge on accumulated dust particles on the PV module and their output voltages. They have been done for measuring the effect of the charge levels of the powder on the PV modules' output voltages. Also it has been investigated for a relation between the amount of charge on the powder particles and the percentage of reduction on the PV modules' output voltage. The effect of charged powder particles (epoxy powder in this work) on the PV modules' output voltage has been measured by using an array of FCs, the LabVIEW software in conjunction with Multifunction 6009 USB DAQ device, and an electronic interface circuit. Two charging processes have been used: (i) corona charging and (ii) tribo charging.

The results have confirmed that increasing the gun voltage (in the corona gun) leads directly to an increase in the net charge value of the powder, which in turn caused more charged powder to build up on the surface of the PV module, and hence, it has decreased their output voltages (even if these PV modules are placed vertically with a 90° tilt angle). Moreover, increasing the tribo gun pressures, it causes in increases the amount of charged powder that adheres to the PV modules' surfaces, and therefore it decreases their output voltages.

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